Renewable and Sustainable Energy Reviews 14 (2010) 790–797

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Solar electricity prospects in Oman using GIS-based solar radiation maps

Adel Gastli [a,*], Yassine Charabi [b,1]

[a] Department of Electrical & Computer Engineering, College of Engineering, Sultan Qaboos University, P.O. 33, Al-Khodh, Muscat-123, Oman
[b] Department of Geography, College of Arts, Sultan Qaboos University, P.O. 42, Al-Khodh, Muscat-123, Oman

ARTICLE INFO

Article history:
Received 16 April 2009
Received in revised form 3 August 2009
Accepted 28 August 2009

Keywords:
GIS
Oman
Prospect
CSP
Concentrated solar power
Solar map
Solar electricity
Solar radiation

ABSTRACT

This paper discusses solar power prospects in Oman. First, the geographic and topographic information about Oman are presented. The methodology of producing solar radiation maps using GIS tools is then discussed. The results obtained show very high potential of solar radiation over all the lands of Oman during the whole year. A slope analysis has allowed calculating the yearly electricity generation potential for different Concentrated Solar Power (CSP) technologies such as the parabolic trough, parabolic dish, tower, and concentrated PV. For instance if only 10% of the land of Oman with a slope less than 1% is considered an exploitable land for the parabolic trough CSP technology, then the total calculated potential of yearly electricity generation would be about 7.6 million GWh, which is many multiples of (680 times) the current generation supply in Oman which was about 11,189 GWh in 2007.

Contents

1. Introduction

The very slow renewable energy development in the Middle East in general and in Oman in particular, facing a multitude of policy and administrative barriers – including highly subsidized cheap electricity competing with renewable technologies – as well as the lack of adequate fiscal incentives to consumers for their private installation, have prevented the spread of renewable energies in the region and the country because of general fear and distrust of renewable energies. Flows of foreign technology and finance were also way below real needs. However, the previous known fear and distrust of renewable energies on the part of Oman as an oil and gas producing country has changed into a realization that renewable energy can be an essential component of its national energy supplies, as well as a global strategic option for both extending the life of oil and gas reserves and reducing carbon dioxide emissions and thus contributing in combating climate change.

The use of solar energy in Oman has been limited to very few applications such as city street lighting, park meters, and few

* Corresponding author. Tel.: +968 24141373; fax: +968 24413454.
E-mail addresses: gastli@squ.edu.om (A. Gastli), yassine@squ.edu.om (Y. Charabi).
[1] Tel.: +968 24142003; fax: +968 24141851.

1364-0321/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2009.08.018

telecommunication stations in remote areas. Positive investment climate, strong property rights, and low tax regimes, adequate regulatory framework, with established participation in the power sector from leading international firms, will certainly provide incentives to more solar energy applications in the country. However, without an accurate database and knowledge of most appropriate locations of renewable energy applications in the country, investment in renewable energy will not be efficient and profitable. This can be achieved by producing solar radiation maps for Oman.

Innovations in solar radiation mapping are now contributing to the rapid growth of solar energy market in many countries. The developed solar radiation maps benefit everyone from home-owners and solar-panel installers to the developers and financiers of large-scale power projects, industry experts, and governments. In addition, with the present worldwide credit crisis and the perilous world and local economy, precise solar maps will be increasingly important as investors seek assurance that deals will be really profitable. Better information means quicker decisions saving money and bringing renewable energy resources into production more quickly. Therefore, finding the right location for installing solar energy systems in Oman is very crucial at this stage.

Developing solar radiation maps for a given region means creating illustrations revealing the geographical distribution of solar radiation covering that specific region. A solar radiation map demonstrates solar energy potentials of a specific region and provides information which is useful for optimum site selection of a solar energy system. A solar radiation map can be generated by using solar radiation data obtained from measurement stations. However, such a method is not applicable to many parts of the globe due to insufficiency of measurement stations. One solution is to use satellite-derived solar radiation data to create solar radiation maps.

In the past 35 years, several methods for estimating solar radiation from satellite data have been developed and used [1–42]. However, only few studies have been carried out for tropical countries such as Oman.

This paper presents a study that aimed at developing the first geographical mapping models to locate the most appropriate sites for different Concentrated Solar Power (CSP) technologies in Oman.

2. Location and topography of Oman

The Sultanate of Oman occupies the South-Eastern corner of the Arabian Peninsula and is located between Latitudes 16°40′ and 26°20′ North and Longitudes 51°50′ and 59°40′ East (Fig. 1). It has a coastal line extending almost 3165 km, from the Strait of Hormuz in the North to the borders of the Republic of Yemen, overlooking three seas; the Arabian Gulf, Gulf of Oman and the Arabian Sea [43].

The Sultanate of Oman borders Kingdom of Saudi Arabia and the United Arab Emirates in the West; the Republic of Yemen in the South; the Strait of Hormuz in the North and the Arabian Sea in the East.

The total area of the Sultanate of Oman is 309,500 km^2, and it is the third largest country in the Arabian Peninsula. The Sultanate of Oman is composed of varying topographic areas consisting of plains, wadis and mountains. The most important area is the plain overlooking the Gulf of Oman and the Arabian Sea with an area of about 3% of the total.

The mountain ranges occupy about 15% of the total, the most important of which are "Al-Hajr mountains", extending in the form of an arch from Ras Musandam in the North to Ras Al-Had and Dhofar mountains in the South-Western corner of Oman. The remaining area is mainly sand and desert which includes part of ArRub Al-Khali occupying about 82% of the total area (Fig. 2).

During the last three decades the country witnessed spectacular socio-economic developments which increase the power electricity demand, in combination with limited gas resources that call for a quantitative assessment of potential of solar energy. Installation of solar concentrator's farms in Oman can be a strong alternative source of producing electrical power. One of the main objectives of this paper is to investigate areas where can these farms be installed with an accurate estimation of their energy potential.

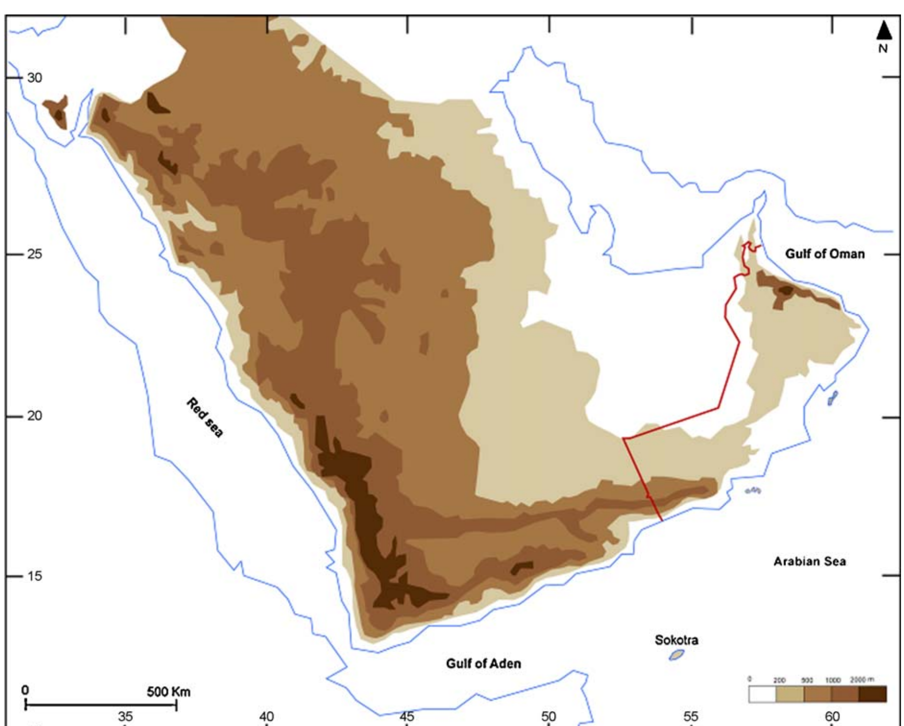

Fig. 1. Location of Oman in the Arabian Peninsula.

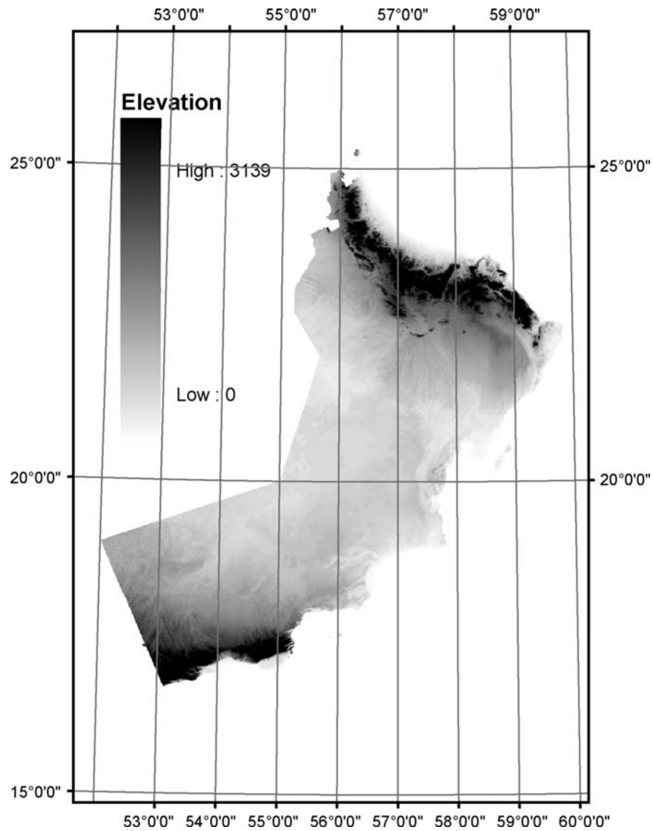

Fig. 2. Digital Elevation Model of Oman.

3. Benefits of designating land for solar development

Government's policy leaders could be proactive in the development of solar energy by identifying appropriate lands for development and creation of a process or processes by which the land could be made available to developers over time. Identifying specific parcels of land to be made available in the future would be very much beneficial as described in Fig. 3.

Reserving specific land areas for solar power installations could be a component part of a master plan for solar development. Designating solar power development land would help avoid a situation where there is insufficient agglomeration of solar energy to justify investments in transmission facilities.

To help create viable solar energy market there is a need to the timely access to land and transmission to deliver electricity generated by solar power to load centers. In general, solar energy projects shall be developed first on the land that is located near existing transmission lines.

Therefore, designating lands for solar development would be a key step to creating a strong solar future for the country and would:

- facilitate the planning of new transmission lines
- attract more solar project developers to build solar generation facilities
- develop new research and development opportunities for solar energy applications
- produce clean and reliable electric power in the country to meet growing energy needs
- create a valuable product to export to other countries especially after the interconnection between Oman and the UAE
- provide jobs in rural and remote areas
- diversify the country's economy and provide more tax revenue

Designating land would definitely require a multi-step process. Step one would consist in conducting process to evaluate the suitability of the lands for solar development, such as energy production potential and environmental sensitivities, and developing maps to delineate potential lands. In the next step, from the obtained information, maps for a master land plan could be created where areas of land are identified as most appropriate for development. Finally, in the case of the Ministry of Housing in Oman, a timetable for auctioning various parcels of land, and the solar-specific process for auctions, could be developed.

Construction of new transmission lines is one of the most discouraging obstacles to building a future solar generation. The existing transmission system will allow some room for new solar generation but a significant expansion of solar power resources will require the building of new transmission lines into tracts that are not currently well served with electricity.

Historically, the lead time for developing new fossil power plants is similar to, and can be coordinated with the construction of new transmission lines. However, renewable energy generation resources can be sited, developed and constructed in much less time than is needed to build new transmission lines. Thus, a timing mismatch is created where a generator will have to wait for transmission or the transmission needs to be built before contracts are signed for a new generation sources. This is financially uncertain situation for solar power developers and transmission

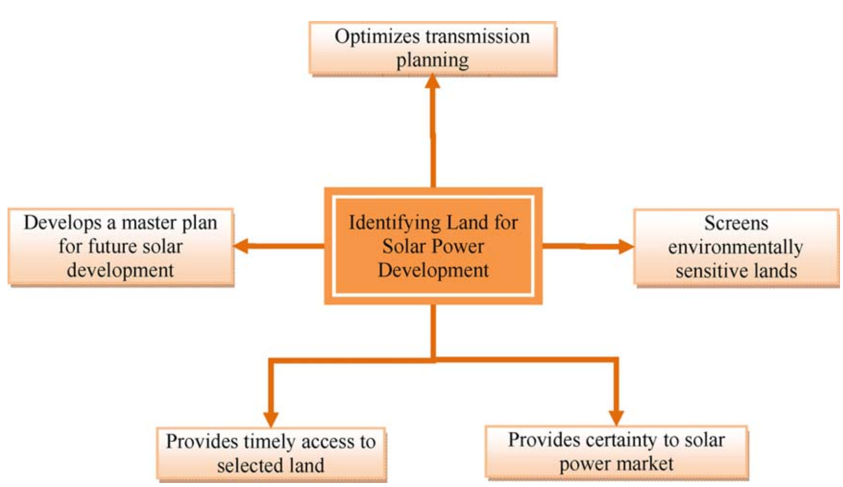

Fig. 3. Benefits of identifying land for solar power development.

utilities. Transmission lines may not be available when solar energy projects become ready to produce electricity and transmission utilities may have an excess in line capacity (costly) if planned solar energy projects are not built. In addition, if solar energy plants are geographically scattered and isolated, there may not be sufficient generation capacity in one place to economically justify investment in new transmission lines. These risks can be somewhat managed by grouping solar energy development in geographically concentrated areas. If an area of future development can be determined, then transmission can be planned and built to the selected area. The transmission can be planned and timed so that the land becomes available in time to develop the solar power generation project.

Designating specific areas of land to be developed will make it easier for transmission planners and project developers to work together to plan, site and build the wires necessary to bring solar energy resource to population centers.

Electric power generation from solar energy is a relatively high land demanding process. As a rule of thumb for concentrating solar power technology, approximately 2.6 km^2 of land (260 ha) is needed to produce approximately one hundred megawatts (100 MW) of power. The total land required for solar power installations varies based on the technology used. For instance, some additional land may be needed if the generation facilities include energy storage. In the desert regions of Oman about 25,000 homes can be served with 100 MW of solar power.

Generally, the selected land areas must be large enough to produce sufficient electric power to support a new transmission line. It is perhaps required to provide more land than is necessary for a project so there is enough siting flexibility, and a possibility to accommodate more than one project to allow future expansion and to create diversity. Land tracts that are 8–13 km^2 would be able to support transmission and multiple projects.

4. Developing solar radiation maps

With landscape scales, topography is a key factor that determines the spatial variability of radiation. Variation in elevation, orientation (slope and aspect), and shadows cast by topographic features all affect the amount of radiation received at different locations. This spatial variability also changes with time of day and time of year. The solar radiation analysis tools, in the ArcGIS Spatial Analyst extension, enables to map and analyze the effects of the sun over a geographic area for specific time periods. It accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography as shown in Fig. 4.

Incoming solar radiation originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is intercepted at the earth's surface as direct, diffuse, and reflected components. The sum of the direct, diffuse, and reflected radiation forms the global solar radiation. In general, direct radiation is the principal component of total radiation, and diffuse radiation is the second largest component. The solar radiation tools in ArcGIS Spatial Analyst [44] do not include reflected radiation in the calculation of total radiation. Therefore, the total radiation is calculated as the sum of the direct and diffuse radiation. The solar radiation tools can perform calculations for point locations or for entire geographic areas. This involves six steps as described by Fig. 5.

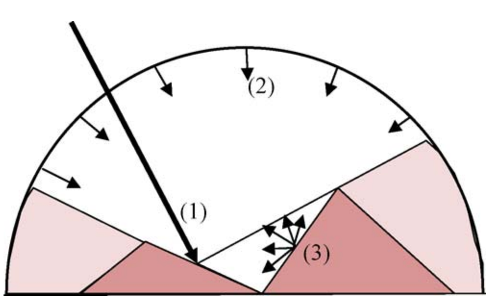

Fig. 4. The three sources of energy on a slope: (1) direct or beam radiation from the sun; (2) diffuse radiation from the sky, where a portion of the overlying hemisphere may be obstructed; and (3) diffuse and direct radiation reflected off of nearby terrain [27].

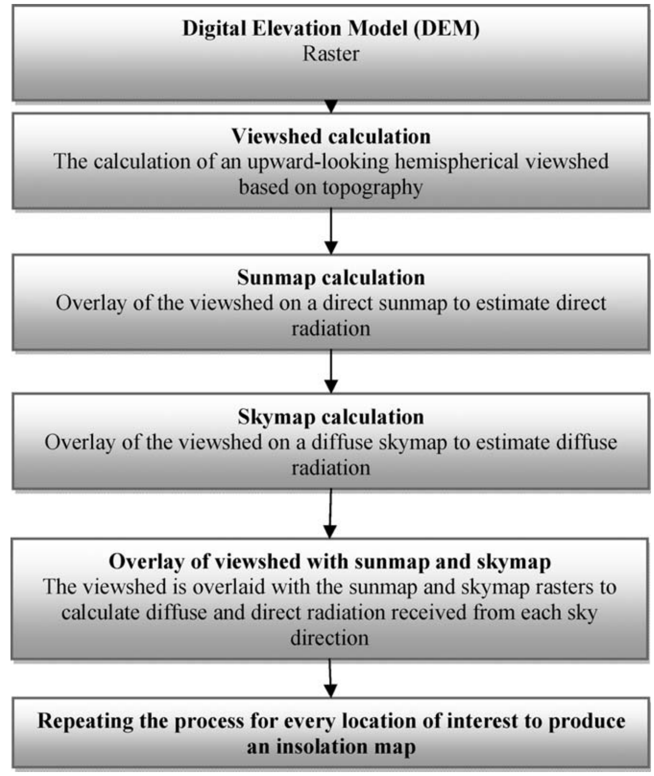

Fig. 5. Steps followed to calculate solar radiation on a DEM using ArcMap.

5. Estimation of electricity generation capacity and potential

It is possible to estimate yearly electric power generation potential of the country or a region based on the calculated yearly solar radiation per unit surface, the total exploitable area, and the efficiency of the technology used to convert solar radiation into electricity. Eq. (1) can be used to estimate the yearly solar electric power generation potential:

$$GP = SR \times CA \times AF \times \eta \quad (1)$$

where all the parameters are defined in Table 1.

Table 2 presents the electric power capacity and efficiency of some existing solar electricity system technologies. The capacities were deduced from [45] and the efficiency ranges were selected based on information available on the Internet.

6. Results and discussions

6.1. Resolution of the DEM

It is important to select an appropriate resolution of the DEM of Oman that can be used with ArcMap tool (part of ArcGIS) so that it

Table 1
Definitions of parameters used in Eq. (1).

Parameter	Definition	Units
GP	The electric power generation potential per year	MWh
SR	The solar radiation received per unit horizontal area	MWh/km^2/year (to calculate annual electricity production)
CA	The calculated total area	km^2
AF	The area factor, indicates what fraction of the calculated areas are solar exploitable	Unitless
η	The efficiency with which solar system converts sunlight into electricity	Unitless

Table 2
Capacity per square kilometer and efficiency of some of solar electricity system technologies [45].

	Capacity MW/km^2	Efficiency range %
Parabolic trough, no storage, <1% slope	43.26	15–21
Parabolic trough, 6 h storage, <1% slope	30.82	15–21
Power tower, 6 h storage, <1% slope	22.38	18–20
Parabolic dish, <3% slope	49.26	25–30
Parabolic dish, <5% slope	49.25	25–30
Concentrating PV, <3% slope	41.11	37–45
Concentrating PV, <5% slope	41.13	37–45

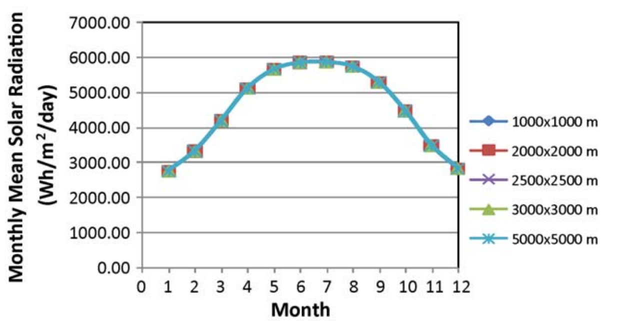

Fig. 6. Monthly mean solar radiation per day obtained for different map resolutions.

can run faster without jeopardizing the accuracy of the results. There is a compromise between obtaining highly accurate results and the software computational time. Therefore, several DEMs have been created with different resolutions ranging between 1000 m × 1000 m and 5000 m × 5000 m per cell. The solar radiation module of the ArcMap was run on all the DEMs. Fig. 6 shows a comparison between the monthly mean solar radiations obtained with different resolution of DEMs.

It is clear from Fig. 6 that there is no significant difference between the different resolutions. Therefore, a resolution of 3000 m × 3000 m cells was adopted which gave a relatively short running time of solar radiation area calculation iterations. Note that we are interested on knowing the global distribution of solar radiation on the total lands of Oman. We are not analyzing these time-specific areas for future CSP installations. This task will require adding other layers of information such as the present and future urban areas, water availability maps, roads and utilities, and sensitive areas. For this type of analysis, a higher DEM resolution may be required.

6.2. Generated solar maps

The daily solar radiations over all the lands of Oman (except for Musnadum region in north of Oman which was not part of the analyzed DEM) were calculated for every month. Table 3 summarizes the obtained results.

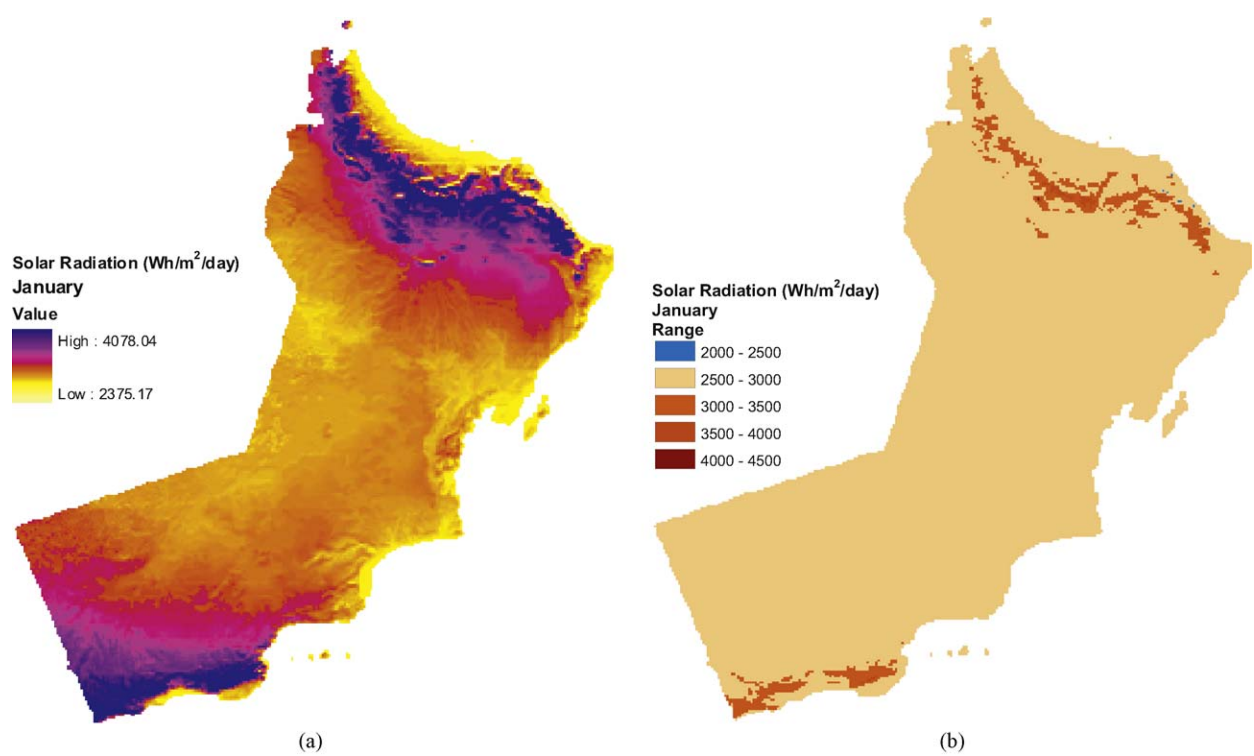

Fig. 7. Solar radiation distribution and classification over the land of Oman during the month of January: (a) distribution, (b) classification.

Table 3
Solar Radiation (Wh/m^2/day) results for a cell size of 3000 m × 3000 m.

Value	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Min	2375	2929	3805	4808	5458	5589	5587	5564	5008	4095	3081	2443
Max	4078	4696	5560	6415	7050	7304	7340	7150	6618	5816	4857	4157
Mean	2770	3338	4202	5130	5673	5869	5884	5756	5305	4479	3491	2840
STDV	107	117	129	140	149	154	154	150	143	132.	119	108

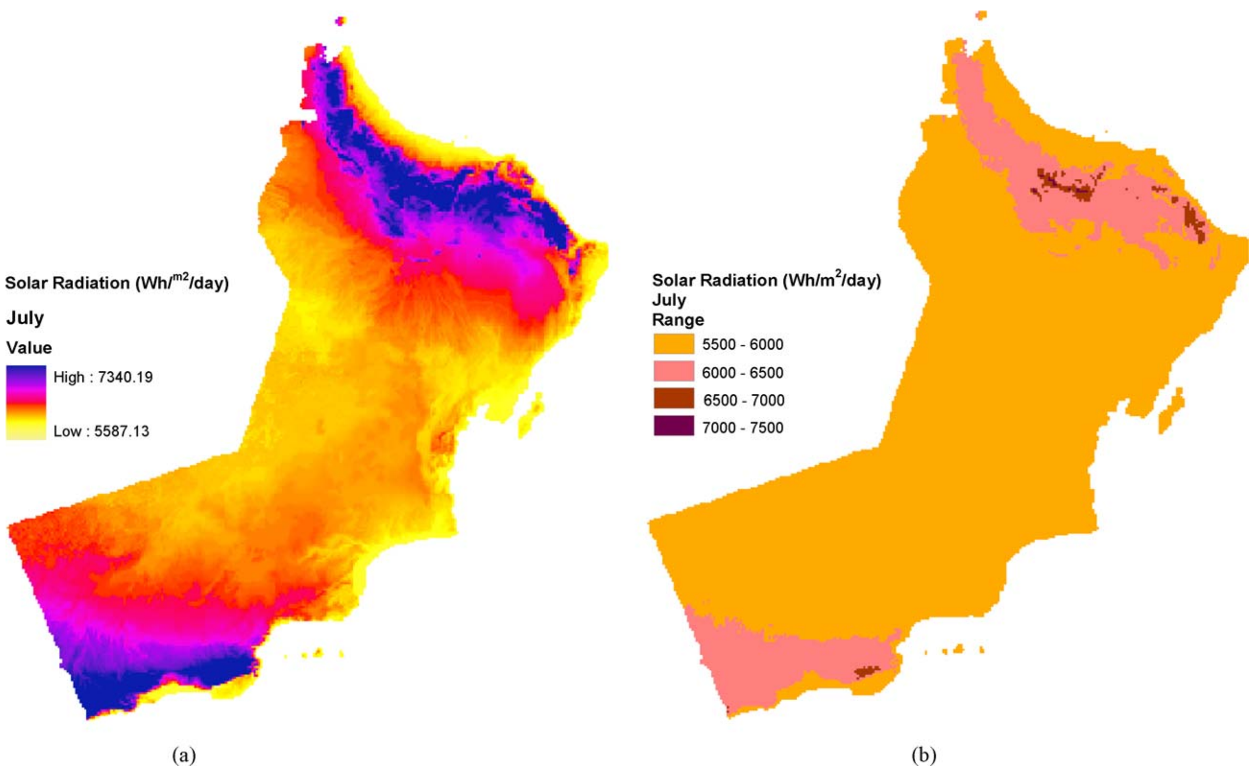

Fig. 8. Solar radiation distribution and classification over the land of Oman during the month of July: (a) distribution, (b) classification.

Notice that the highest solar radiation per day is obtained during the month of July (summer solstice) and the least one is obtained in January (winter solstice).

Figs. 7 and 8 show the solar radiation distribution and classification over the lands of Oman during the months of January and July, respectively.

Notice that the majority of the land in Oman receives daily solar radiations ranging between 5500–6000 Wh/m^2/day and 2500–3000 Wh/m^2/day in July and January, respectively. This shows that there is a very high potential of solar energy in Oman.

The total annual solar radiation per m^2 is shown in Fig. 9(a) and the slope classification of the land areas is given in Fig. 9(b).

Notice again that a large portion of the lands in Oman have very similar yearly potential of solar radiation. In addition, a majority of the lands have slopes below 1% (flat land). This signifies that it is easy to implement large CSP plants with different technologies such as parabolic trough, parabolic dish, tower, and concentrated PV technologies without additional and expensive work over to flatten the lands. The land areas for each technology type, along with the potential generation capacity in MW and GWh/year, are presented in Table 4 where an area factor AF = 10% was selected arbitrarily. The efficiency η of each CSP technology was selected based on the average values of the ranges given in Table 2.

Table 4
Summary of obtained results.

AF = 10%	Total solar resource land area, CA (km^2)	Total capacity potential (MW)	Total solar radiation, SR (MWh/km^2/year)	Generation potential, GP (GWh/year)
Parabolic trough, no storage, <1% slope	253,519	1,096,725	423,246	7,618,421
Parabolic trough, 6 h storage, <1% slope	253,519	781,347	423,246	7,618,421
Power Tower, 6 h storage, <1% slope	253,519	567,376	423,246	8,041,666
Parabolic Dish, <3% slope	288,041	1,418,890	480,799	13,221,970
Parabolic Dish, <5% slope	299,081	1,473,276	499,212	13,728,336
Concentrating PV, <3% slope	288,041	1,184,137	480,799	19,712,755
Concentrating PV, <5% slope	299,081	1,229,524	499,212	20,467,701

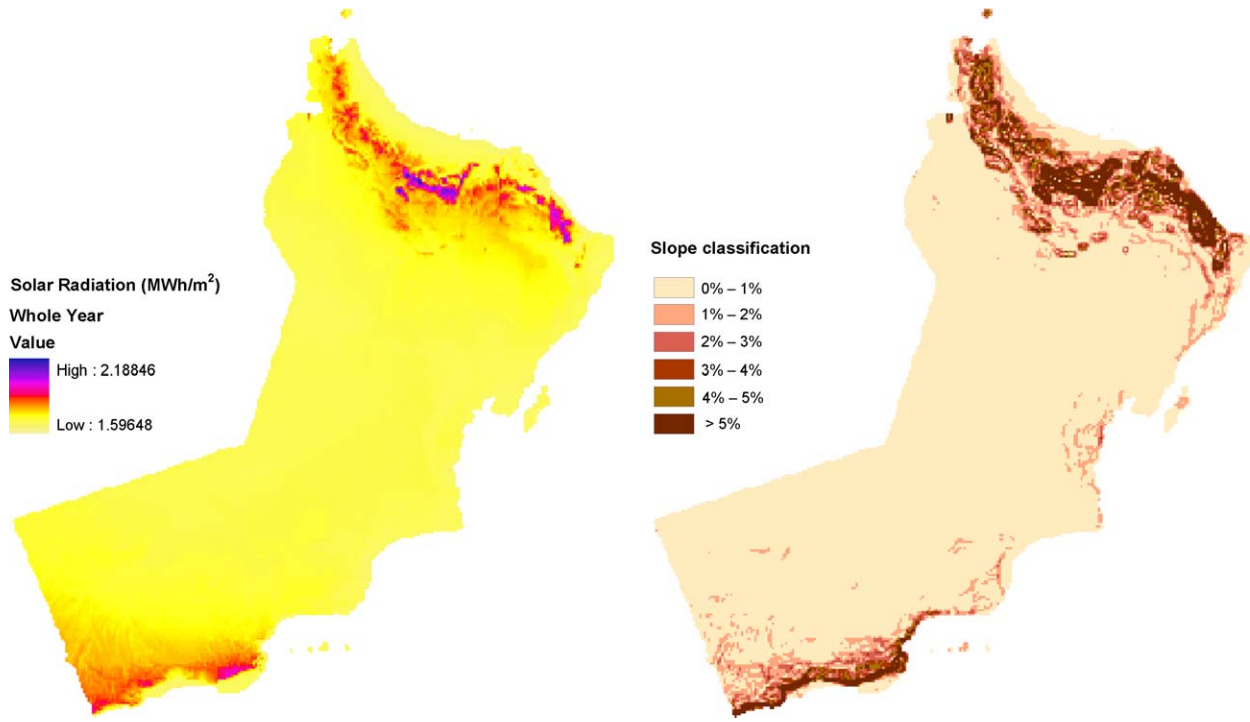

Fig. 9. Yearly solar radiation density and slopes classification over the land of Oman: (a) yearly solar radiation in Wh/m^2, (b) classification of slopes in percent.

Table 4 shows that, with each CSP technology, there is the potential to generate many multiples of the current demand for electricity in Oman. The total generation capacity as of 2009 for Oman was roughly 3000 MW and the electricity supply for 2007 was around 11,189 GWh [46].

7. Conclusion

This paper presented a study on solar electricity prospects in Oman using GIS-based solar radiation maps. These maps are the first of their kinds to be published in the literature and will benefit government's policy leaders to be proactive in the development of solar energy and will help create viable solar energy market. The methodology followed to generate such maps was based on the ArcMap tools embedded in the ArcGIS Software. It is important to note that in situ measurement realized with pyranometers, will not be able to capture the spatial variability in radiation caused by topography as the GIS does.

The results obtained showed very high potentials of solar energy and solar electricity generation on most of the lands of Oman during the whole year. The high ratio of sky clearness (about 342 days/year) and the geographical location of Oman played an important role in awarding this country with a very high potential of solar electricity generation.

The developed GIS solar radiation database will have the capability to communicate with other models such as feasibility and cost analyses, combination of solar energy with other sources of energies (hybrid applications).

In future studies, the area factor will be estimated more accurately after incorporating data on urban and populated areas, roads, rivers, and sensitive areas into the maps and taking into account future planning and developments of the country. Moreover, higher resolution maps will be used for selected regions of high potential in order to have more accurate study of specific solar projects' implementations.

References

[1] Vonder Haar T, Raschke E, Bandeen W, Pasternak M. Measurements of solar energy reflected by the earth and atmosphere from meteorological satellites. Solar Energy 1973;14:175–84.
[2] Tarpley JD. Estimating incident solar radiation at the surface from geostationary satellite data. Journal of Applied Meteorology 1979;18:1172–81.
[3] Gautier C, Diak G, Masse S. A simple physical model to estimate incident solar radiation at the surface from GOES satellite data. Journal Applied Meteorology 1980;36:1005–12.
[4] Iqbal M. An introduction to solar radiation. Academic Press: New York; 1983.
[5] Moser W, Rachke E. Incident solar radiation over Europe from METEOSAT data. Journal of Climate and Applied Meteorology 1984;23:166–70.
[6] Sorapipatana C, Exell RHB, Borel D. A bispectral method for determining global solar radiation from meteorological satellite data. Solar and Wind Technology 1988;5(3):321–7.
[7] Sorapipatana C, Exell RBH. Mesoscale mapping of daily insolation over South-east Asia from satellite data. Solar and Wind Technology 1989;6(1):59–69.
[8] Diabate L, Moussu G, Wald L. Description of an operation tool for determining global solar radiation at ground using geostationary satellite images. Solar Energy 1989;42(3):201–7.
[9] Exell RHB. Mapping solar radiation by meteorological satellite. Renewable Energy Review Journal 1984;6.(1).
[10] Cano D, Monget J, AlbuissonM M, Guillard H, Regas N, Wald L. A method for the determination of the global solar radiation from meteorological satellite data. Solar Energy 1986;37:31–9.
[11] Zelenka A. Satellite versus ground observation based model for global irradiation. In: Proceedings of the INTERSOL 85 Congress; 1986. p. 2513–7.
[12] Dedieu G, Deschamps PY, Kerr YH. Satellite estimation of solar irradiance at the surface of the Earth and Surface albedo using a physical model applied to METEOSAT data. Journal of Climate and Applied Meteorology 1987;26:79–87.
[13] Perez R, Ineichen P, Seals R, Michalsky J, Stewart R. Modeling daylight availability and irradiance components from direct and global irradiance. Solar Energy 1990;40(5):271–89.
[14] Czeplak G, Noia M, Ratto CF. An assessment of a statistical method to estimate solar irradiance at the earth's surface from geostationary satellite data. Renewable Energy 1991;1(5/6):737–43.
[15] Nunez M. The development of a satellite-based insolation model for the tropical western Pacific Ocean. International Journal of Climatology 1993;13:607–27.
[16] Dubayah R. A solar radiation topoclimatology for the Rio Grande river basin. Journal of Vegetation Science 1994;5:627–40.
[17] Famiglietti JS, Wood EF. Multi-scale modeling of spatially-variable water and energy balance processes. Water Resource Research 1994;30(11):3061–78.
[18] Pinker RT, Kustas WP, Laszlo I, Moran MS, Huete AR. Basin-scale solar irradiance estimates in semiarid regions using GOES 7. Water Resource Research 1994;30:1375–86.

[19] Rich PM, Dubayah R, Hetrick WA, Saving SC. Using Viewshed models to calculate intercepted solar radiation: applications in ecology. American Society for Photogrammetry and Remote Sensing Technical Papers 1994;524–9.
[20] Pinker RT, Laszlo I. Modelling surface solar irradiance for satellite applications on a global scale. Journal of Applied Meteorology 1995;31:194–211.
[21] Abdulla F. Regionalization of a macroscale hydrological model. Water Resources Series Technical Report 1995;144:198.
[22] Dubayah R, Rich PM. Topographic solar radiation models for GIS. International Journal of Geographical Information System 1995;9:405–19.
[23] Palz W, Greig J. European solar radiation atlas. Heidelberg: Springer; 1996.
[24] Beyer HG, Costanzo C, Heinemann D. Modifications of the heliosat procedure for irradiance estimated from satellite images. Solar Energy 1996;56:207–12.
[25] Dubayah R, Loechel S. Modeling topographic solar radiation using GOES data. Journal of Applied Meteorology American Meterological Society 1997;36:141–55.
[26] Hirunlabh J, Sarachitti R, Namprakai P. Estimating solar radiation at the earth's surface from satellite data. Thammasat International Journal of Science and Technology 1997;1:69–79.
[27] Von Hoyningen-Huene W, Schmidt T, Schienbein S, Kee CA, Tick LJ. Climate-relevant aerosol parameters of South-East-Asian forest fire haze. Atmospheric Environment 1999;33:3183–90.
[28] Zelenka A, Perez R, Seals R, Renne D. Effective accuracy of the satellite-derived hourly irradiance. Theoretical and Applied Climatology 1999;62:199–207.
[29] Hammer A, Heinemann D, Lorenz E, Luckehe B. Short-term forecasting of solar radiation: a statistical approach using satellite data. Solar Energy 1999;67:139–50.
[30] Ineichen P, Perez R. Derivative of cloud index from geostationary satellites and application to the production of solar irradiance and daylight illuminance data. Theorectical Applications of Climatology 1999;64:119–30.
[31] Rich PM, Fu P. Topoclimatic habitat models. In: Proceedings of the fourth international conference on integrating GIS and environmental modeling; 2000.
[32] Fu P. A geometric solar radiation model with applications in landscape ecology. PhD thesis. USA: Department of Geography, University of Kansas, Lawrence Kansas; 2000.
[33] Fu P, Rich PM. The solar analyst 1.0 manual. USA: Helios Environmental Modeling Institute (HEMI); 2000.
[34] Perez R, Ineichen P, Moore K, KmiecikM, Chain C, George R, et al. A new operational for satellite-derived irradiances: description and validation. Solar Energy 2002;73(5):307–17.
[35] Fu P, Rich PM. A geometric solar radiation model with applications in agriculture and forestry. Computers and Electronics in Agriculture 2002;37:25–35.
[36] Wyser K, O'Hirox W, Gautier C, Jones C. Remote sensing of surface solar irradiance with corrections for 3-D cloud effects. Remote Sensing of Environment 2002;80:272–84.
[37] Perez R, Ineichen P, Kmiecik M, Moore K, Renne D, George R. Producing satellite-derived irradiances in complex arid terrain. Solar Energy 2004;77:367–71.
[38] Schillings C, Mannstein H, Meyer R. Operational method for deriving high resolution direct normal irradiance from satellite data. Solar Energy 2004;76:475–84.
[39] Janjai S, Laksanaboonsong J, Nunez M, Thongsathitya A. Development of a method generating operational solar radiation maps from satellite data for a tropical environment. Solar Energy 2005;78:739–51.
[40] Janjai S, Wanvong W, Laksanaboonsong J. The determination of surface albedo of Thailand using satellite data. In: Proceeding of the 2nd joint international conference on sustainable energy and environment (SEE2006) Bangkok; 2006.p. 156–61.
[41] Martins FR, Pereira EB, Abreu SL. Satellite-derived solar resource maps for Brazil under SWERA project. Solar Energy 2007;81:517–28.
[42] Vignola F, Harlan P, Perez R, Kmiecik M. Analysis of satellite derived beam and global solar radiation data. Solar Energy 2007;81:768–72.
[43] Statistical year book. Sultanate of Oman: Ministry of National Economy; 2006, http://www.moneoman.gov.om/stat_book/2006/fscommand/english/ins/genin.htm.
[44] ArcGIS Help Manual. ESRI ArcGIS 9.2.
[45] NREL California solar benefit report; April 21, 2006.
[46] Annual report. Oman: Authority for Electricity Regulation; 2007 (www.aer-oman.org).